Research Paper | Education | E-ISSN No : 2454-9916 | Volume : 9 | Issue : 5 | May 2023

HEAT TRANSFER IN A SQUARE CAVITY FILLED WITH TITANIA NANOFLUID

Supreeti Das

Gargi College, Delhi University

ABSTRACT

The current work focusses on the natural convection developed in a square cavity with differentially heated vertical walls, filled with nanofluid. The nanofluids under consideration is TiO_2 in base fluids water, EG and oil. Thermophysical properties namely specific heat and thermal conductivity have been evaluated for all the three base fluids for volume fractions 1%-10% . Results from these evaluations have been used to estimate the Nusselt numbers along the hot wall, for varying volume fractions, using the correlations derived from literature. Effect of the Rayleigh number which is representative of the difference in the temperature between the two walls, on the Nusselt number, has also been investigated. It is concluded that the Nusselt number increases as the volume fraction of the nanoparticle increases. Further, convection heat transfer mode is activated at a lower volume fraction for water nanofluid compared to EG and oil nanofluids. Increase of Nusselt number with volume fraction implies that the addition of titania nanoparticles delays the onset of convection, implying that the system becomes unstable for higher Rayleigh numbers in comparison to the base fluids.

KEYWORDS: Nanofluid, Natural Convection, Square -Cavity, Nusselt Number

INTRODUCTION

Nanofluids have emerged as an innovative material for efficient heat transfer. In the last three decades there has been a lot of experiments on the effect of augmenting conventional heat removing fluids with nanoparticles and nanotubes. The general conclusion is that there is, an enhancement in heat transfer characteristics with the increase in the concentration of the added nanoparticles [1]. Nanofluids, when passing through cooling channels do not clog the channel and the effect of general wear and tear of the walls of the pipes is reduced in comparison to the earlier solid microparticle based heat transfer fluids. Nanofluids as an effective heat transfer medium, has applications in solar distillation [2], food processing industry [3], automobile industry as coolants [4], electronic cooling [5], light weight heat exchangers in aviation [6], CPU cooling [7], petroleum industry [8,9] and in the refrigeration system [10]. These nanofluids also find applications in renewable energy technologies. However, there being a deluge of data for different nanofluids, in this paper the focus is only on the TiO_2 nanofluid which has some unique properties and hence diverse applications. A lot of studies have been carried out for its enhanced performance in renewable energy technologies. Ebaid et.al [11] added TiO_2nanoparticles to water -polyethylene glycol base fluid for Photovoltaic module's thermal management. The output of the cell increased by 6.05% in comparison to the base fluid. Subramani et al. [12] studied the effect of concentration of TiO_2nanoparticles on the parabolic trough collector's efficiency. Their base fluid was DI water and the concentration range under consideration was 0.05%-0.5%. An increase in the convective heat transfer was observed and the collector had the best efficiency at a 0.2% concentration which was 8.66% higher in comparison to water as the coolant. Moravej et al. [13] used TiO_2water nanofluid in a flat-plate solar collector and observed an increase in efficiency with the volume fraction of the nanoparticle. Ding et.al [14] concluded that employing TiO_2 nanofluid as coolants in energy systems, enhanced the performance with minimal carbon emission. This nanofluid is very effective in comparison to carbon nanotubes and graphene [15] though the thermal conductivity of titanium di oxide is much lower but some of its properties have drawn special attention. TiO_2 nanofluids have experimentally been found to have good dispersibility. Agglomeration and sedimentation result in the formation of inhomogeneous dispersions which is detrimental to quick heat transfer. TiO_2 nanoparticles have the unique feature of high dispersivity in water, EG and oil resulting in the formation of a well dispersed nanofluid for better thermal management. A detailed analysis on the stability of TiO_2and zinc oxide nanofluid has been done by Roslan et.al.[16]. They have also stated that these nanofluids have a special application in the oil recovery explorations. The production of TiO_2involves a simplified process [17] and hence designing nanofluids with these nanoparticles for efficient heat removal, at the industrial scale, can be economically quite viable.TiO_2 has a special property of efficient absorption and is an important component for the cosmetic industry particularly in sunscreens. Hence nanofluid derived from it is also environmentally safe [18]. The objective of the current work is to investigate natural convection employing TiO_2 nanofluids for real world application [19]. Addition of TiO_2 nanoparticles to the base fluid increases its viscosity [20] and hence the pumping cost. Zhong et al. [21] explored the flow of TiO_2 nanofluids through a mini channel. They observed a 14.9% rise in viscosity at 1% volume fraction of the nanoparticle. To reduce this cost, the concentration of the nanoparticle should be low, contributing to minimal increase in the viscosity. Variation of the thermophysical properties of TiO_2 nanofluid with volume fraction for different base fluids is an essential study for all heat transfer applications [22-25]. The current work will involve studying the variation of thermophysical properties with volume fraction of the nanoparticle. A special application will also be investigated considering a square cavity filled with this nanofluid. Heat transfer will be evaluated for the cavity with differentially heated vertical walls. Variation of Nusselt number with Rayleigh number as well as its variation with the volume fraction of TiO_2 nano particle will be considered.

DESCRIPTION OF THE PROBLEM

In the current work the thermophysical properties of TiO_2 nanofluid will be considered using the correlations developed [26]. The concentration of the nanoparticle will be in the range of 1% -10%. Thus, the basic assumption is that flow of nanofluids with such small volume fractions of nanoparticles can be treated as a single- phase flow. The presence of nanoparticles just alters the thermophysical properties of the base fluid. To simplify computation, the research is confined to the laminar flow regime. Multi-phase flow and turbulent regime will be considered elsewhere. Since natural convection is a very important heat transfer mode for thermal engineering applications like cooling in nuclear reactors, solar energy, pipe flow, the focus in this paper will be on heat transfer in a square cavity under natural convection. The vertical walls are differentially heated and are maintained at constant temperatures. The horizontal walls are considered as thermal insulators. Velocity- profile and temperature distributions are solutions of the Navier Stoke's equation and the energy equation [27]. In order to test the onset of convection, Nusselt number will be evaluated along the hot wall for a range of Rayleigh numbers for all the three base fluids augmented with Titania nanoparticles using the correlations developed by Palessa et.al. [28].

Material	Density (kg/m^3)	Specific Heat (J/kg K)	Thermal conductivity (W/mK)	Viscosity (Pa-s)
TiO_2	4250	686.2	8.95	
Water	998	4197	0.613	0.001
E.G.	1110	2400	0.26	0.016
Oil	884	1910	0.144	0.0135

Table 1: Thermophysical Properties

RESULTS

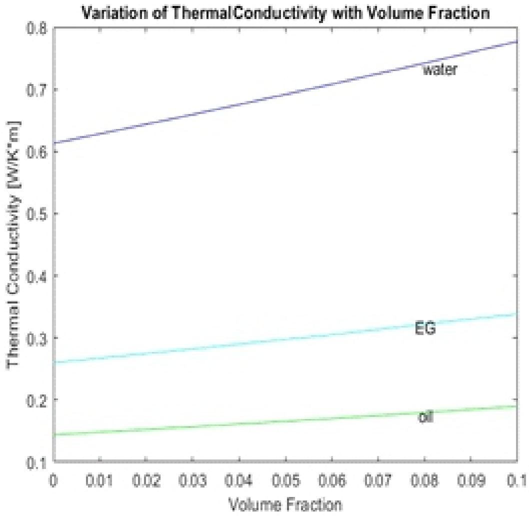

Figure 1: Thermal Conductivity vs Concentration

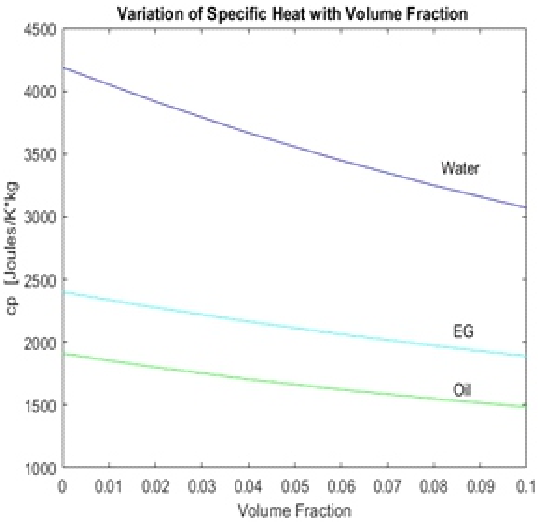

Figure 2: Specific Heat vs concentration

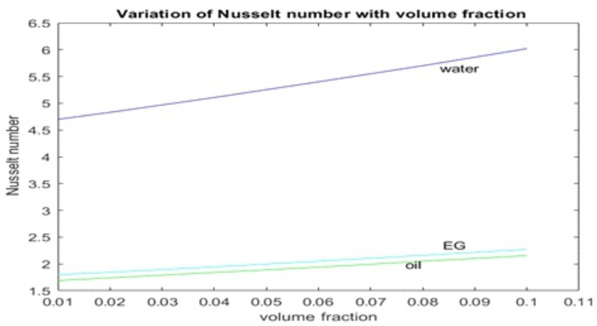

Figure 3: Nusselt number as a function of volume fraction of TiO_2 nanoparticles

CONCLUSION

Variation of thermophysical properties with volume fraction confirms the enhancement in thermal conductivity with concentration (Figure 1) for the Titanium di oxide nanofluids added to base fluids, water, Ethylene Glycol and oil. However, the specific heat capacity decreases with volume fraction which means that the base fluids have the highest specific heat. The evaluation of Nusselt number for the square cavity, along the hotter wall, with varying concentrations is represented in Fig. 3. This evaluation has been done for Rayleigh number (Ra) 10^5. With the increase in the nanoparticle volume fraction, there is an increase in Nusselt number. The other conclusion from this investigation is that the heat transfer by convection mode becomes significant for smaller volume fractions of titania when the base fluid is water. EG and oil have almost similar behaviour and the convection mode of heat transfer will become dominant for higher Ra keeping the concentration of nanoparticles fixed.

For future applications, hybrid nanofluids can be designed for efficient heat removal at the industrial scale with the special emphasis on environmentally friendly and economically viable options. Further, it is imperative to understand the fluid dynamics and heat transfer in layers of nanofluids for real world applications and hence more experimental results are needed for deriving the correlations and formulating new models which can include more parameters for effective thermal management [29].

REFERENCES

1. Liu Yang, Kai Du,A comprehensive review on heat transfer characteristics of TiO2 nanofluids,International Journal of Heat and Mass Transfer,Volume 108, Part A, 2017, Pages 11-31, ISSN 0017-9310 https://doi.org/10.1016/j.ijheatmasstransfer.2016.11.086.
2. G.N. and Sahota, L., 2017, Advanced solar distillation systems: Basic Principles thermal modelling and its application, Springer, ISBN 978-981-10- 4672-8
3. Saeed Salari, Seid Mahdi Jafari,Application of nanofluids for thermal processing of food products, Trends in Food Science & TechnologyVolume 97, March 2020, Pages 100-113
4. Hafiz Muhammad Ali et al, 2015, "Experimental Investigation of Heat Transfer Augmentation for Car Radiator using Zno-Water Nanofluids", Energy Vol. 84,pp 317-324.
5. M.U. Sajid, H.M. Ali, Recent Advances in application of nanofluids in heat transfer devices: A critical review, Renew. Sustain. Energy Rev. 103 (2019) 556–592.
6. Jatin Patel , Abhishek Soni , Divya P. Barai , Bharat A. Bhanvase , A minireview on nanofluids for automotive applications: Current status and future perspectives, Applied Thermal Engineering, Vol 219, Part A, 25 Jan,2023,119428
7. M. Nazari, M. Karami, M. Ashouri, Comparing the thermal performance of water, Ethylene Glycol, Alumina and CNT nanofluids in CPU cooling: Experimental study, Exp. Therm Fluid Sci. 57 (2014) 371–377
8. A. Sircar, K. Rayavarapu, N. Bist, K. Yadav, S. Singh, Applications of nanoparticles in enhanced oil recovery, Petroleum Res. 7 (1) (2022) 77–90.
9. S.U. Ilyas, R. Pendyala, N. Marneni, Stability of nanofluids, Topics Mining,Metallurgy Mater. Eng. 1–31 (2017), https://doi.org/10.1007/978-3-319-29761-3_1.
10. Jiang W, Li S, Yang L, Du K. Experimental investigation on performance of ammonia absorption refrigeration system with TiO2 nanofluid. Int J Refrig 2019;98:80–8. doi: https://doi.org/10.1016/j.ijrefrig.2018.09.032
11. Ebaid MSY, Ghrair AM, Al-Busoul M. Experimental investigation of cooling photovoltaic (PV) panels using (TiO2) nanofluid in water -polyethylene glycol mixture and (Al2O3) nanofluid in water- cetyltrimethylammonium bromide mixture. Energy Convers Manag 2018;155:324–43. doi: https://doi.org/10.1016/J.ENCONMAN. 2017.10.074.
12. Subramani J, Nagarajan PK, Mahian O, Sathyamurthy R. Efficiency and heat transfer improvements in a parabolic trough solar collector using TiO2 nanofluids under turbulent flow regime. Renew Energy 2018;119:19–31. doi: https://doi.org/10.1016/j.renene.2017.11.079.
13. Moravej M, Bozorg MV, Guan Y et al. Enhancing the efficiency of a symmetric flat-plate solar collector via the use of rutile TiO2- water nanofluids. Sustain Energy Technol Assess 2020;40:100783. doi: https://doi.org/10.1016/j.seta.2020.100783.
14. Ding M, Liu C, Rao Z. Experimental investigation on heat transfer characteristic of TiO2-H2O nanofluid in microchannel for thermal energy storage. Appl Therm Eng 2019;160:114024. doi: https://doi.org/10.1016/j.applthermaleng.2019.114024.
15. O. Mahian, L.Kolsi, M. Amani et al.,2018"Recent advances in modelling and simulation of nanofluid flows-Part I: Fundamental and theory", Physics Reports, 10.1016/j.physrep.2018.11.004
16. A.A. Roslan, Siti Nur Azella Zaine, H. Mohd Zaid et al. Engineering Science and Technology, an International Journal 37 (2023) 101318
17. Majid I. Abdulwahab , S.M.Thahab and Asmaa H.Dhiaa,Experimental Study of Thermophysical Properties of TiO2 Nanofluid,Iraqi Journal of Chemical and Petroleum Engineering Vol.17 No.2 (June 2016) 1- 6 ISSN: 1997-4884.
18. Ayyab Raza Shah, Chao Zhou and Hafiz Muhammad Ali Titanium Dioxide: Advancements and Thermal Applications , 2021,DOI: 10.5772/intechopen.101727
19. Osman Turan ,Anuj Sachdeva , Nilanjan Chakraborty , Robert J. Poole, Laminar natural convection of power-law fluids in a square enclosure with differentially heated side walls subjected to constant temperatures, Journal of Non-Newtonian Fluid Mechanics,Vol.166,Issues 17-18,Sept.2011,1049-1063.
20. Viscosity of nanofluid
21. Zhong D, Zhong H, Wen T. Investigation on the thermal properties, heat transfer and flow performance of a highly self-dispersion TiO2 nanofluid in a multiport mini channel. Int Commun Heat Mass Transf 2020. doi: https://doi.org/10.1016/j.icheatmasstransfer.2020.104783
22. Wei B, Zou C, Li X. Experimental investigation on stability and thermal conductivity of diathermic oil based TiO2 nanofluids. Int J Heat Mass Transf 2017;104:537–43. doi: https://doi.org/10.1016/ J.IJHEATMASSTRANSFER.2016.08.078.
23. Yiamsawasd T, Dalkilic AS, Wongwises S (2012) Measurement of the thermal conductivity of titania and alumina nanofuids. Thermochim Acta 545:48–56
24. Kumari Swati et al 2020 Nano Ex. 1 010051
25. Reddy MCS, Rao VV. Experimental studies on thermal conductivity of blends of ethylene glycol-water-based TiO2 nanofluids. Int Commun Heat Mass Transf 2013;46:31–6. doi: https://doi.org/10.1016/ j.icheatmasstransfer.2013.05.009
26. Palesa Helen Mlangeni, Zhongjie Huan, Thembelani Sithebe, Vasudeva Rao Veeredhi, "Prandtl Number and Viscosity Correlations of Titanium Oxide Nanofluids", Journal of Engineering, vol. 2023, Article ID 4949566, 10 pages, 2023. https://doi.org/10.1155/2023/4949566
27. S.Chandrashekhar, Hydrodynamic and Hydromagnetic stability, Dover publication,1961
28. R Prakash et al 2023 J. Phys.: Conf. Ser. 2484 012035, Turbulent natural convection heat transfer enhancement of nanofluids
29. Ali Komeili Birjandi, Misagh Irandoost Shahrestani, , Akbar Maleki,et. al.Thermal conductivity estimation of nanofluids with TiO2 nanoparticles by employing artificial neural networks. International Journal of Low-Carbon Technologies 2021, 16, 740–746, https://doi.org/10.1093/ijlct/ctab00